NASA TECHNICAL NOTE

NASA TN D-2449

NASA TN D-2449

STUDY OF CONTAMINATION-INDUCED LUMINOSITY AHEAD OF A BLUNT BODY IN THE LANGLEY HOTSHOT TUNNEL

by William D. Harvey and William V. Feller

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1964

STUDY OF CONTAMINATION-INDUCED LUMINOSITY AHEAD OF A BLUNT BODY IN THE LANGLEY HOTSHOT TUNNEL

By William D. Harvey and William V. Feller

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Office of Technical Services, Department of Commerce,
Washington, D.C. 20230 -- Price $0.50

STUDY OF CONTAMINATION-INDUCED LUMINOSITY AHEAD OF A BLUNT BODY IN THE LANGLEY HOTSHOT TUNNEL

By William D. Harvey and William V. Feller
Langley Research Center

SUMMARY

A spectrographic study of the contamination-induced luminosity behind a blunt-body shock wave in the Langley hotshot tunnel has been made. The study was conducted at a Mach number of 20 in nitrogen for a stagnation temperature of 3000° K and pressure of 12,000 psi. Both time-integrated and time-resolved spectra were obtained. Some of the species are identified. It was found that the occurrence of the luminosity was in short-duration bursts at variable times from shot to shot. Blackbody radiation was either absent or too weak to record.

INTRODUCTION

Numerous photographs have been published of the self-luminous flow around blunt bodies in hotshot tunnels. It has usually been assumed that the light is due to incandescence of the contamination material which is known to exist in these tunnels. There does not seem to have been, however, a specific study of the nature of the light emitted nor of the time of occurrence and duration of the emission.

If the emission were of the blackbody type, it would be possible to use the well-known two-color optical pyrometry technique to measure temperatures in the flow field around a blunt body. This possibility led to the present study in which spectra were obtained of the light emitted from the stagnation region of a blunt body in the Langley hotshot tunnel. The study was conducted at a Mach number of 20 in nitrogen for a stagnation temperature of 3000° K and a pressure of 12,000 psi. At these conditions, there is no appreciable dissociation or ionization of equilibrium nitrogen. Both time-integrated and time-resolved spectra were obtained.

APPARATUS AND TESTS

Tunnel

The Langley hotshot tunnel is a conventional hotshot tunnel with an arc chamber in which a high-energy arc is discharged to raise the temperature and pressure of the test gas, a conical nozzle and test section, and a vacuum

reservoir. The facility and its operation are fully described in reference 1. The arc chamber used in the present tests (fig. 1) is the coaxial electrode arrangement described in appendix A of reference 1 (without the magnetic coil.) At the time of the present study only a few measurements of contamination in the tunnel test section using the present arc chamber were available. These were in the form of measurements of the mass increase of circular aluminum disks exposed normal to the flow for the entire duration of a run, as described in reference 1. The mass collected per unit area divided by the calculated mass flow of gas per unit area over the duration of the flow can be used as an estimate of the average contamination level. A contamination level of 1 percent or less was determined by this method. These measurements, however, give no indication of when the contamination occurs or of fluctuations in concentration.

Model

The model used in this investigation was a 2-inch by 6-inch by 1-inch bar of aluminum, sting mounted on the tunnel axis with a broad face perpendicular to the flow. A pressure orifice was located in the center of the upstream face. A photograph of the model is shown in figure 2(a). A time exposure of the self-luminous flow around this model is shown in figure 2(b).

The optical instrumentation to obtain spectra of the glow in front of the model is shown schematically in figure 3. An achromatic lens collects light from the desired region and focuses it on the entrance slit of the spectrograph. The spectrograph is an $f/6.3$ plane grating device with reflecting optics and has a dispersion at the film plane of about 20 angstroms per millimeter. The entire visible spectrum was covered. In order to get a usable exposure on the film, a very wide entrance slit (about 200 microns) was found necessary.

Alinement of the system on a selected part of the flow pattern was made by means of an auxiliary system, the "light gun," shown on the right side of the tunnel. This was simply a point-arc light source and lens arrangement to project an image of the arc on the selected point in the flow field. The collecting lens and spectrograph were lined up on the axis of this beam, and the collector lens was adjusted to focus a sharp image on the spectrograph entrance slit.

With this alinement, the origin of the spectrum observed could be ascribed to a fairly definite volume of the flow field because light from other regions was not in focus on the spectrograph slit. It was estimated that most of the light entering the spectrograph originated in a cylindrical volume about 1/8 inch in diameter tangent to the model face and extending about 2 inches along the face.

Two types of spectral records were obtained: time exposures, for which the shutter in the spectrograph was open for the entire duration of the flow, and time histories, for which the film holder was permitted to free fall past the exit aperture of the spectrograph during the time of flow. A contact carried by the film holder slid along a resistance wire connected across a

battery, forming a slide-wire potentiometer. The voltage picked off by the moving contact was recorded on an oscillograph along with arc-chamber pressure, pitot pressure, and timing signals. The film holder was released at a preset interval before the tunnel firing by a solenoid-operated trigger. On all records, a mercury discharge-tube spectrum was recorded on the film to provide a wavelength calibration and to indicate the initial position of the film for the time-history tests.

RESULTS AND DISCUSSION

An ordinary front-lighted photograph of the model in the tunnel test section is shown in figure 2(a). Figure 2(b) was taken with the camera in the same place as for figure 2(a) but without any external lighting. Such a time exposure, in which the shutter is open for the entire duration of the flow, gives no indication of the time during the run at which the light was emitted or of the duration of the light.

Time-Integrated Spectra

Time exposures of the luminosity spectrum emitted were initially made for the purpose of identifying the type of emission and are shown in figure 4. The spectra from two runs are shown. The conditions for the two runs were nominally the same, but the intensities of the various lines and bands are somewhat different. The 200-micron-wide entrance slit required on the spectrograph in order to obtain adequate exposure on the film resulted in excessively broad spectral lines. The location of the center of a line could be measured to only about ±0.5 angstrom unit on well-defined lines, and to ±1 angstrom unit on broad, or closely spaced lines. This made identification of the lines by wavelengths somewhat uncertain. It was felt, however, that even with poor resolution, positive identification of some of the elements could be made by searching for series of lines or multiplets. The NBS Revised Tables of Multiplets (ref. 2) was used to identify a line by wavelength as belonging to a particular multiplet of an element. If all the other members of that multiplet, of sufficient intensity, could then be located in the spectrum with measured wavelengths agreeing within ±0.5 angstrom of the tabulated value and with the qualitatively correct relative intensities compared with the other members of that multiplet, then the identification of these lines was considered reasonably certain and other multiplets of the same element were examined.

In this manner, lines due to copper, iron, sodium, and chromium were identified as shown in figure 4. The tentative identifications of a calcium line and a manganese triplet are less certain, because members of only one multiplet could be located or accounted for. A number of bright lines could not be identified because they could not be fitted to any multiplet as a result of intensity or wave-length discrepancies.

For the spectral bands, the fine structure could not be resolved, so identification rested on band-head wavelength, direction of degradation, and qualitative intensity distribution (ref. 3). The identified bands are the calcium

fluoride (CaF_2) orange, yellow, and green systems; copper fluoride (CuF_2) yellow and green systems; and cyanogen (CN) red and violet systems. The band at the red end of the spectrum may be due to calcium oxide but the band head is not well defined, so no positive identification can be made.

The line and band spectra show that the emitting materials are in the gas phase. This result could have been anticipated, for at the pressure existing at the stagnation point of the model, about 1 psi, the boiling point of copper from reference 4 is about 2370° K and of iron about 2530° K, while the calculated stagnation temperature of the test gas is about 3000° K, so even if the contaminants are not in thermal equilibrium with the gas some vaporization should occur.

The black or gray body spectrum to be expected from incandescent solid or liquid particles at 3000° K has its maximum intensity at about 9660 Å, beyond the range covered on the film. However, the calculated intensity distribution for a blackbody at 3000° K shows a smooth decrease in intensity with decreasing wavelength such that the intensity at 5200 Å should be about half that at 6200 Å. No such continuous exposure can be seen on the spectrum. Therefore, although it cannot be said that there is no blackbody radiation present, it is clear that the contribution from incandescent particles is very small compared with that of the line and band spectra in the visible range.

The materials identified in the spectra originate in the arc chamber. In particular, fluorine occurs only in the electrode insulation. The materials in contact with the hot test gas are shown in the schematic drawing of the arc chamber (fig. 1). Most of the exposed surface is high purity copper in the liner, end plate, and inner electrode. This electrode and the liner are visibly eroded after each shot. The trigger wire is commercial piano wire and is vaporized almost completely during each shot. The wire and possibly the steel outer electrode are probably the source of the iron, manganese, and chromium. The exposed steel in the throat approach and the tungsten throat insert do not deteriorate noticeably even after 20 to 50 shots, so these can probably be neglected as sources of contamination. The electrode insulators are teflon (tetrafluoroethylene) with a filler containing among other things, calcium oxide and silica. At the conditions existing in the arc chamber, it is very likely that some of the teflon decomposes to release fluorine for reaction with the copper and calcium.

During the present series of tests, it was noticed that the amount of damage to the insulators and the brass trigger wire screw was quite variable from shot to shot. In most shots, the insulators were charred or broken. Sometimes, however, the insulators were so little damaged as to be reusable after wiping the surface clean. The brass screw was usually undamaged, but occasionally was found completely fused. This tends to corroborate the variability indicated by the spectra.

Time-Resolved Spectra

The time-resolved spectrograms obtained by allowing the film holder to fall freely during a run are shown in figure 5. The mercury reference spectrum exposed on the film indicates the rest position of the film prior to free fall. The spectrograph exit aperture height is indicated by the mercury reference spectrum. As the film holder fell during the run, the film was exposed at points farther from the rest position. The finite height of the exit slit caused an integrating effect as each point of the time axis was exposed for the time the film took to travel the distance of the slit height. In each case, the time of flow start was obtained from the pressure records.

Each of the records shows a short-duration spectrum some time after flow start, but the time and duration of the bursts varied for the several runs. Pulses occurred at 45, 50, and 16 milliseconds. A fourth record was obtained with a pulse at 33 milliseconds but the trace was too faint to reproduce. Blackbody continuum was either absent or too weak to record on the film for each record. The most intense species are identified on the figures.

Intensity-Time Traces

Selected lines and bands were scanned along the time axis of two of the time-resolved spectrograms with a densitometer. The lines scanned were CaF_2 at $\lambda = 6064$ Å, Na at $\lambda = 5890$ Å, Cu at $\lambda = 5105$ Å, Mn at $\lambda = 4031$ Å, and CN at $\lambda = 3883$ Å. Figure 6(a) shows film-density variations with time for the record shown in figure 5(a). The density scale for the plots in figures 6(a) and 6(b) is arbitrary. The line densities for all species peak approximately at the same time but with different magnitudes. The duration of the emission is approximately 2 milliseconds, taking into account the aperture height. The shapes of the traces are not identical, but because of the lack of calibration of the film sensitivity, it is not considered practical to make quantitative conclusions from the shapes of the traces.

Figure 6(b) is a similar densitometer scan of the spectrum shown in figure 5(b). All the species contribute light in the same overall time interval, but while the CaF_2, Na, and Mn show two peaks of intensity, the Cu and CN show only one. The relative intensities of the several species are also somewhat different from those in figure 6(a). The durations are estimated to be less than 1 millisecond for the first peak and 3 milliseconds for the second peak. Again, no quantitative conclusions should be made from the shapes of the traces, but the relative intensities of the several species do seem to vary between the two shots.

The time of occurrence of the flashes of light does not correlate with perturbations in the measured model pressure in any of the shots made. It cannot be established at this time if they correspond to variations in the amount of flow contamination.

A tentative explanation for the occurrence of the short-duration flashes at variable times is proposed as follows: the arc column during discharge is probably more contaminated by materials from the electrode assembly and is much hotter than the rest of the gas in the arc chamber. This gas column does not mix rapidly in the time scale of the hotshot tunnel but swirls around the arc chamber, and when a swirl passes the throat entrance some of the gas expands down the tunnel. This hotter-than-average and possibly more contaminated gas is the source of the light burst observed.

CONCLUDING REMARKS

A spectrographic study has been conducted at a Mach number of 20 in the Langley hotshot tunnel to investigate the luminosity ahead of a blunt body.

All of the elements identified in the spectra obtained are present in the arc chamber and some of them occur only in the electrode assembly. The occurrence of the line and band spectra shows that the major light emission is from a gas phase. Blackbody radiation from incandescent particles was either absent or too weak to record on the film. The test did not give quantitative results for the relative concentrations of the radiating materials, but qualitatively, the composition seems to vary from shot to shot. The light was found to occur in short-duration bursts which occurred at times varying from 16 to 50 milliseconds after flow initiation. A tentative mechanism to explain the observed behavior is that the arc-column material does not mix rapidly with the change of test gas, but swirls around the arc chamber. When a swirl passes the nozzle entrance some of the gas expands down the nozzle, and because it is either hotter or more contaminated than the test gas, produces the short, intense burst of light on being brought to rest at the stagnation region of a blunt body.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., March 30, 1964.

REFERENCES

1. Smith, Fred M., Harrison, Edwin F., and Lawing, Pierce L.: Description and Initial Calibration of the Langley Hotshot Tunnel With Some Real-Gas Charts for Nitrogen. NASA TN D-2023, 1963.

2. Moore, Charlotte E.: A Multiplet Table of Astrophysical Interest. Revised ed., N.B.S. Tech. Note 36, U.S. Dept. Commerce, Nov. 1959.

3. Pearse, R. W. B., and Gaydon, A. G.: The Identification of Molecular Spectra. Third ed., Chapman & Hall, Ltd. (London), 1963.

4. Perry, John H., ed.: Chemical Engineers' Handbook. Third ed., McGraw-Hill Book Co., Inc., 1950.

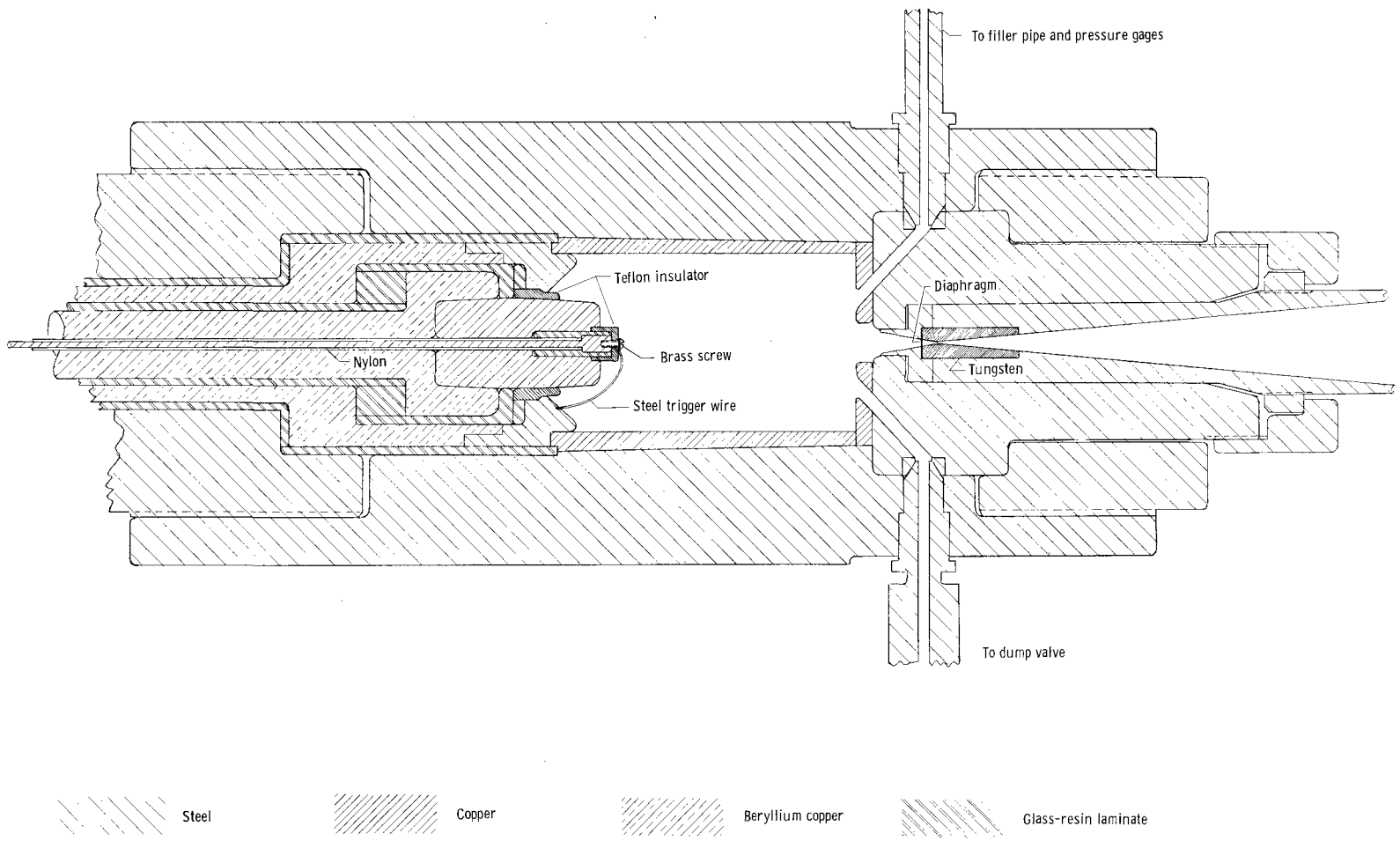
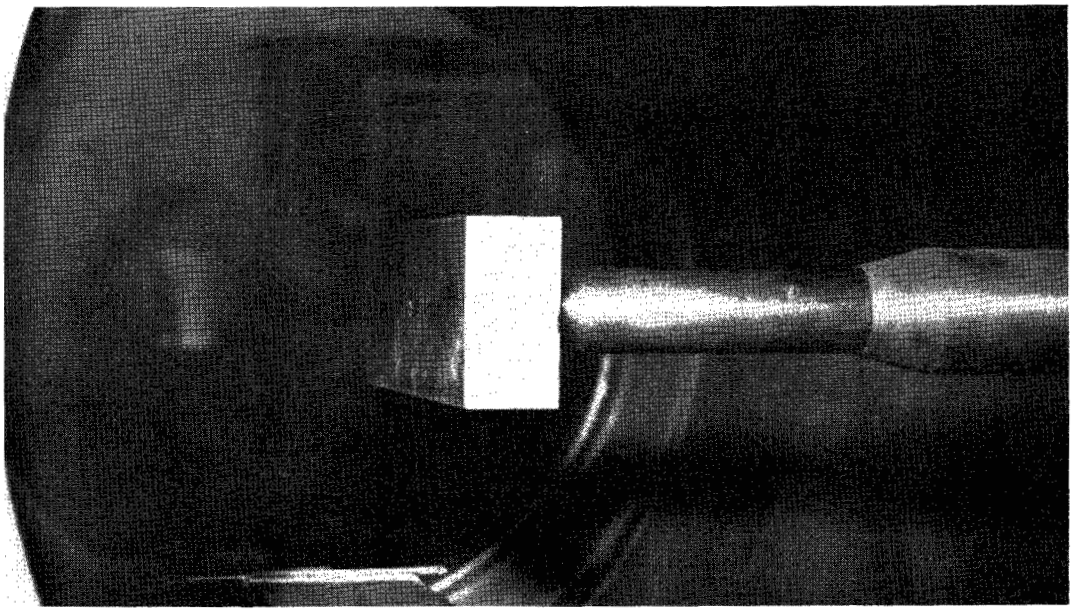
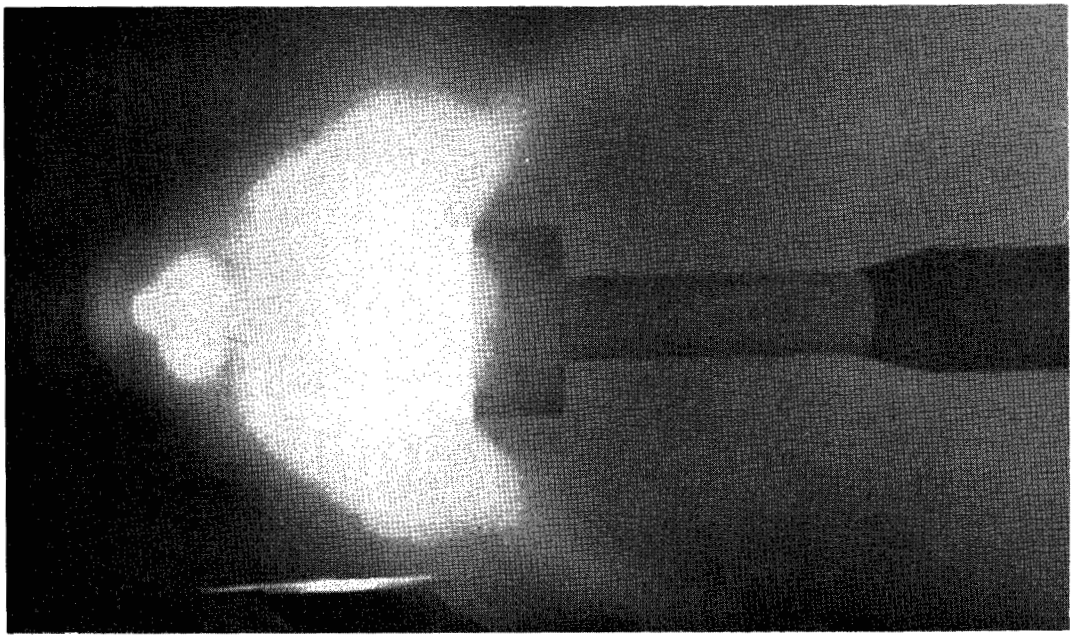


Figure 1.- Schematic of tunnel arc chamber with material components identified.



(a) No flow; front lighted.



(b) Self-luminous. L-64-3029

Figure 2.- Time exposure of self-luminous flow over flat-faced model in Langley hotshot tunnel. $M \approx 20$; $T_0 \approx 3000^\circ$ K.

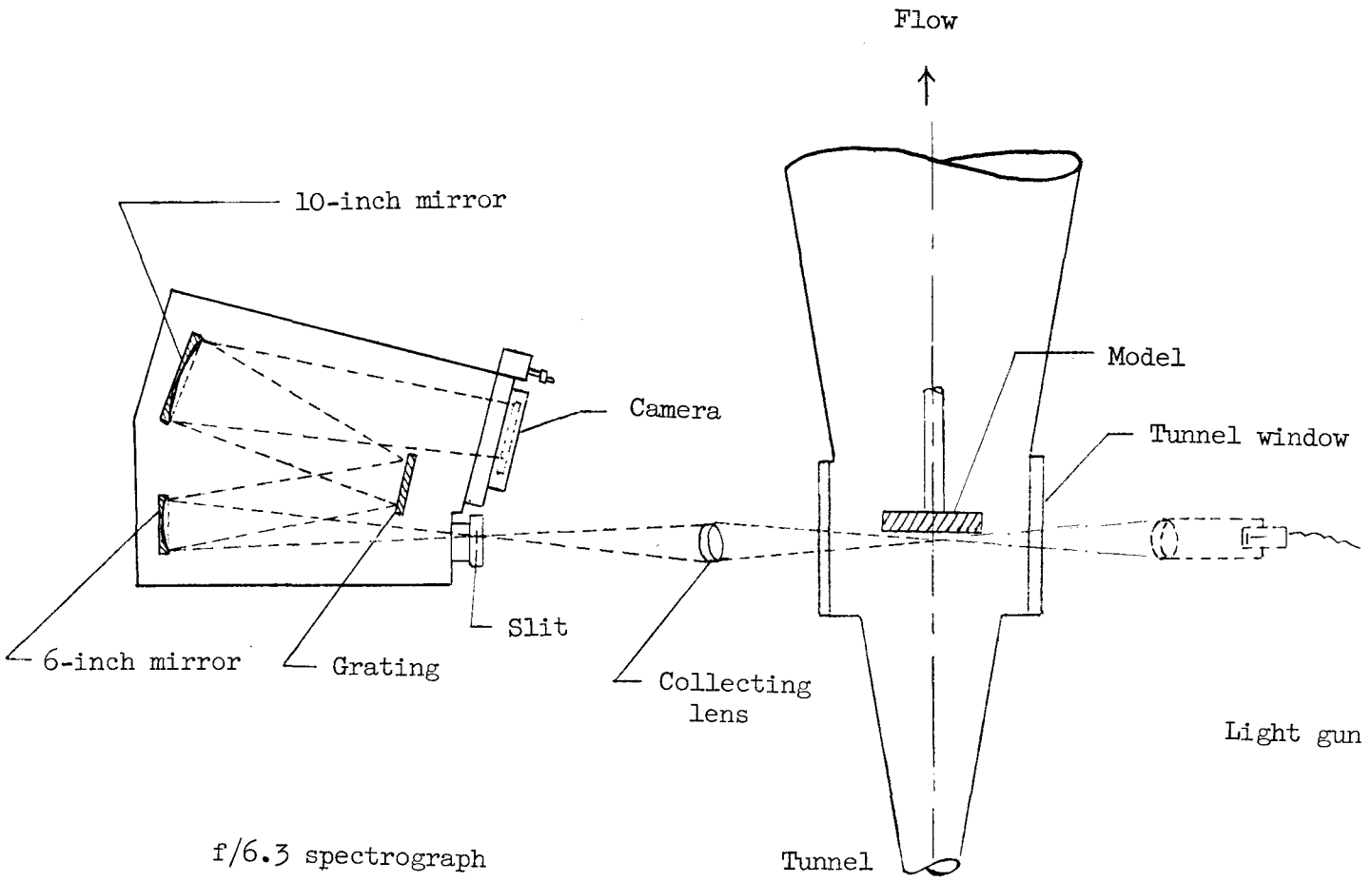


Figure 3.- Optical arrangement for recording spectra of light emitted from flow around model.

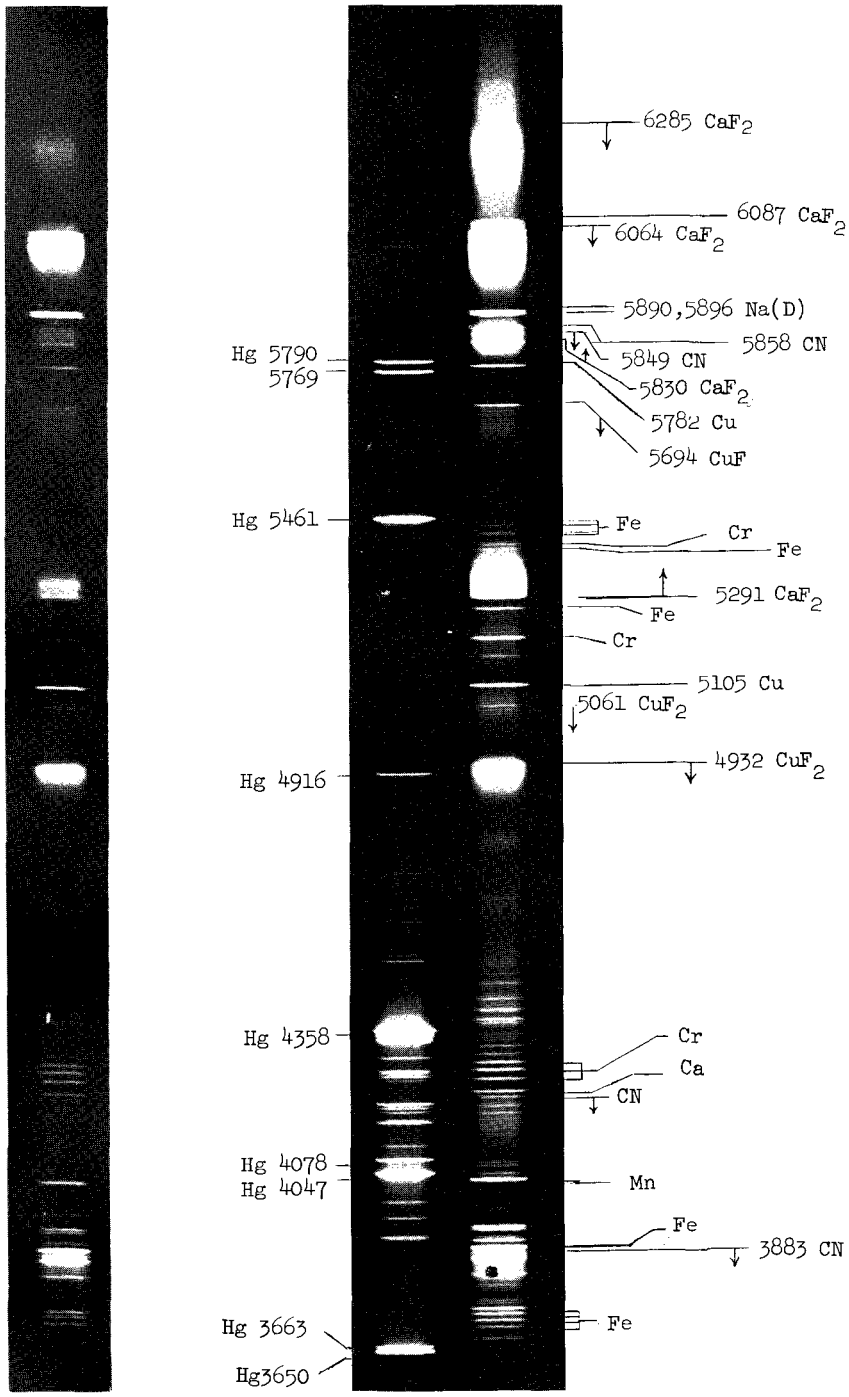
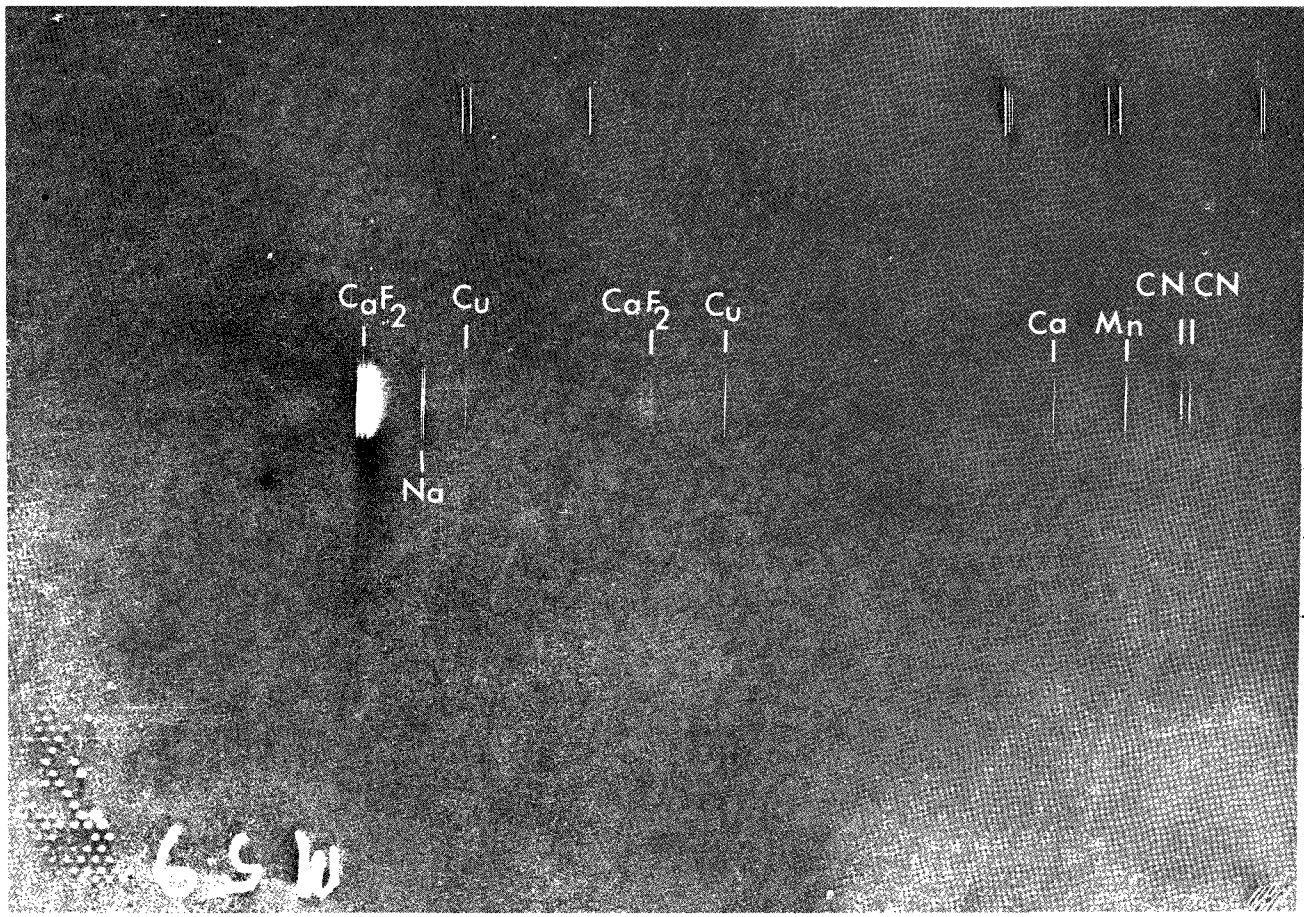
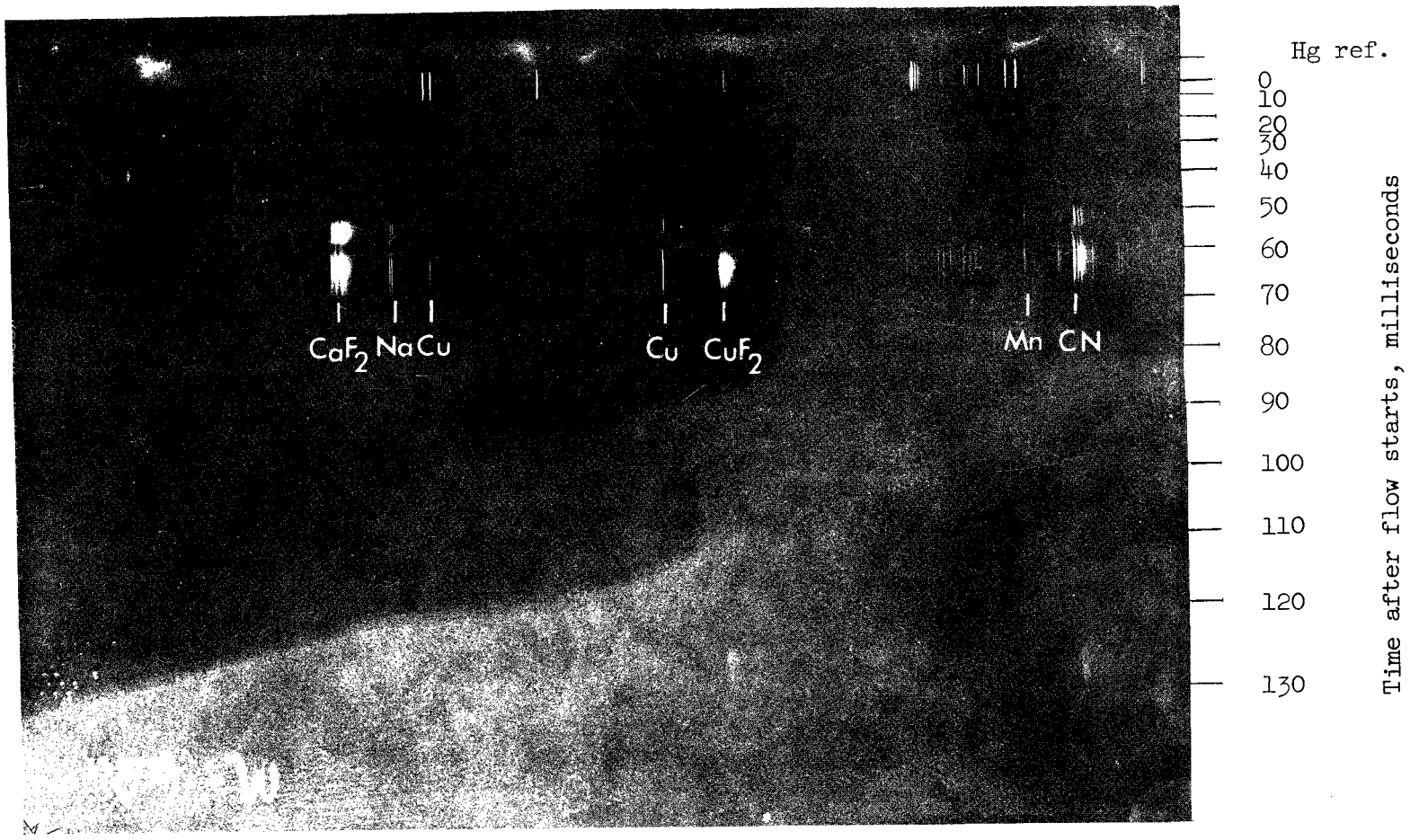


Figure 4.- Time exposures of spectrum from gas cap. Mercury discharge-tube comparison spectrum. Spectrometer slit width, 200μ.



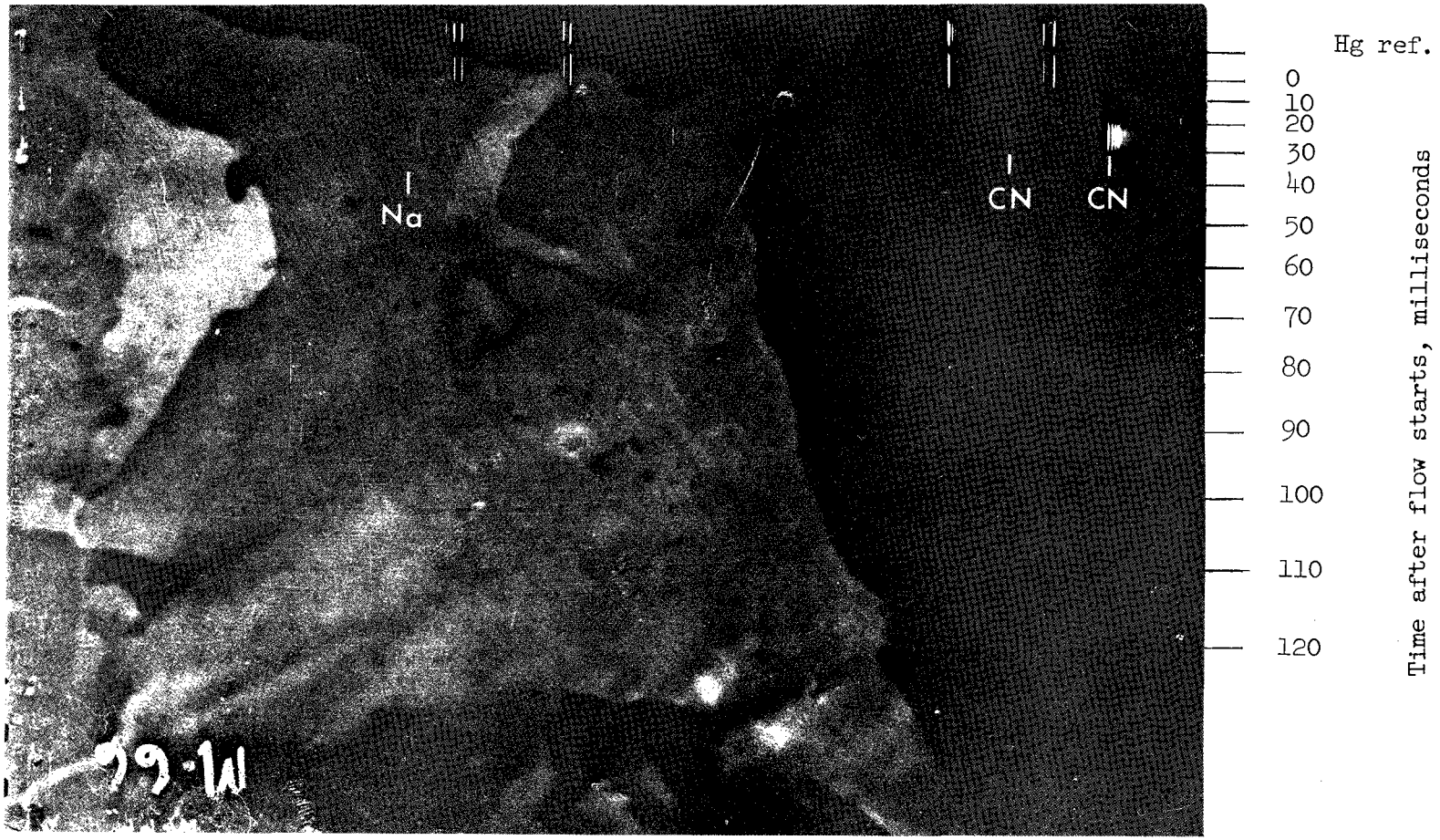
(a) Shot M-59.

Figure 5.- Time-resolved spectrum of emitted luminosity.



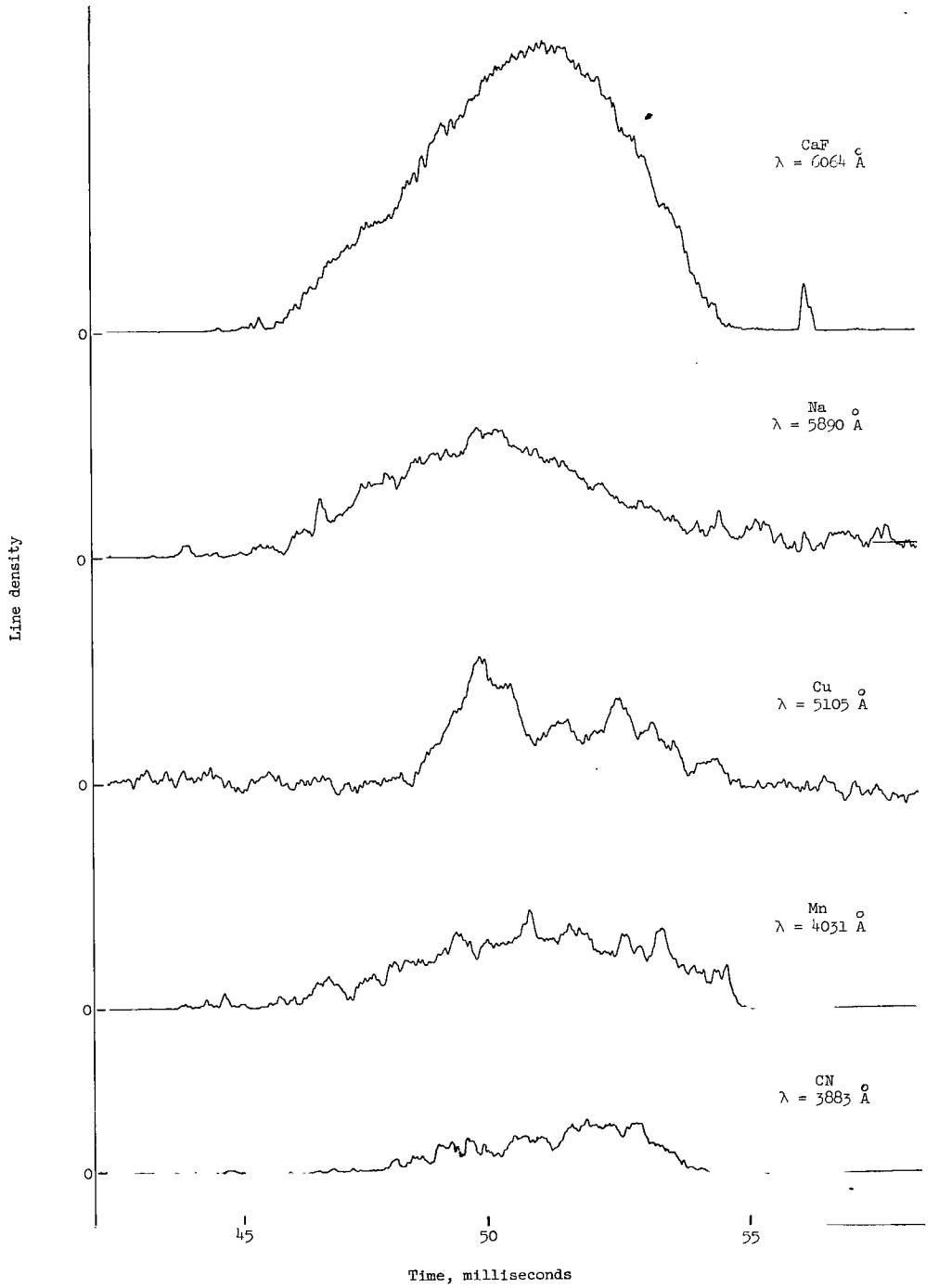
(b) Shot M-60.

Figure 5.- Continued.



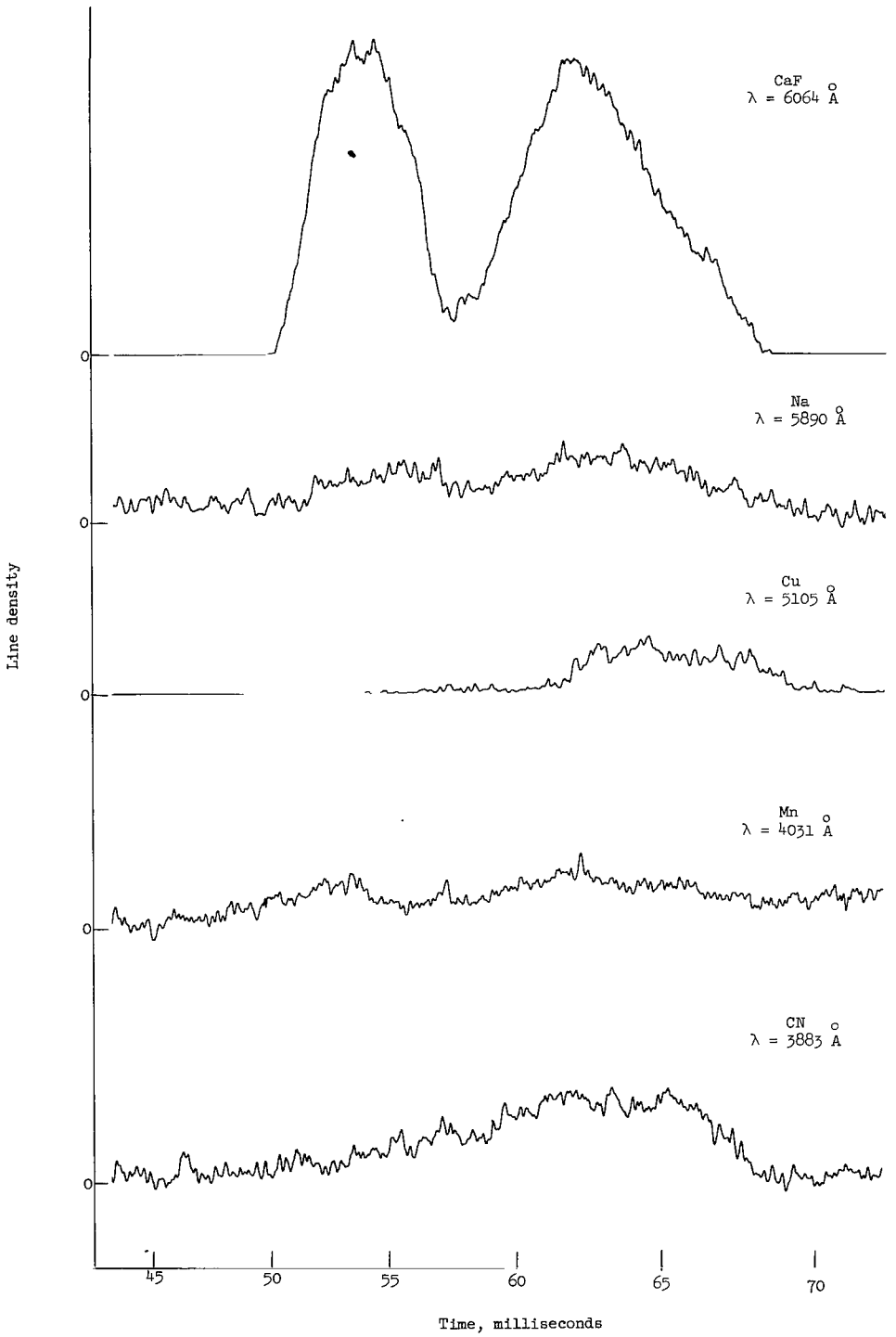
(c) Shot M-66.

Figure 5.- Concluded.



(a) Shot M-59.

Figure 6.- Line density-time traces of some selected spectral lines.



(b) Shot M-60.

Figure 6.- Concluded.

NASA-Langley, 1964 L-3827

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546